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Exploring the feasibility and value of RPAS in the wildfire domain

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The Government of Alberta's Wildfire Management Branch utilizes helicopter and fixed wing aircraft to perform infrared scanning and reconnaissance missions throughout the province. Remotely piloted aircraft system (RPAS) technology platforms have become cheaper and more effective in terms of payload capacity, sensor packages, and flight times. The Government of Alberta is seeking to find ways to increase operational efficiency, and RPAS technology may be able to fill a niche in wildfire management operations.

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INTRODUCTION

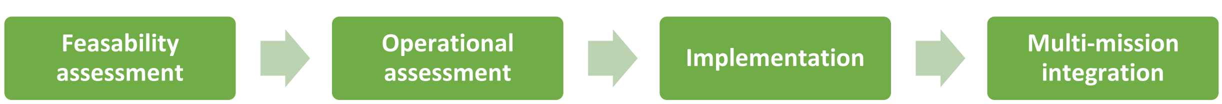
The Government of Alberta's Wildfire Management Branch utilizes helicopter and fixed wing aircraft to perform infrared scanning and reconnaissance missions throughout the province. Operation of crewed aircraft is costly and comes with its own inherent risks. Remotely piloted aircraft system (RPAS) technology platforms have become cheaper and more effective in terms of payload capacity, sensor packages, and flight times. The Government of Alberta is seeking to find ways to increase operational efficiency, and RPAS technology may be able to fill a niche in wildfire management operations.

There are several perceived benefits of using RPAS for intelligence gathering that could extend to wildfire prevention in the form of stand assessments that calculate fuel loading and other characteristics. There is potential for the Wildfire Management Branch to save money and reduce the inherent risks associated with having personnel in low/slow flying aircraft, compared to a remotely piloted aircraft (RPA).

Recent advances in legislation pave a path for long-distance missions beyond visual line of sight through special flight operations certificates (SFOC). Flights were previously restricted to an unaided visual line of sight, thus having a large negative impact on agility and efficiency.

The RPAS and operator should be able to provide support for missions conducted beyond line of sight and fireline intelligence gathering, such as hotspot detection, fire behaviour analysis, smoke column characterization, and atmospheric weather gathering.

In the current state of practice within the province, there has been limited research conducted to understand RPAS capabilities within the wildfire domain. The RPAS was assessed based on its accuracy for collecting data followed by an operational assessment. These two assessment phases will provide crucial knowledge for decisions on where and when to most effectively use RPAS within wildfire mitigation and response, and then ultimately progress to multi-mission integration. This project covers, in part, the feasibility assessment of RPAS specifically focusing on use cases where the technology may provide value to operations. Pegasus Imagery Ltd. (hereafter referred to as "vendor") was chosen for assessment under the following methodology.



OBJECTIVES

1. Assess the efficacy of RPAS to provide accurate hotspot location information.
2. Explore the ability of RPAS to provide fire behaviour and other relevant intelligence on active wildfires.

METHODS

Phase 1: Hinton infrared grid accuracy and efficacy assessment

The objective of this phase was to assess the efficacy of the RPAS vendor in accurately detecting and mapping the locations of simulated hotspots during a night-time monitoring activity. This assignment allowed the RPAS vendor to showcase the accuracy of their infrared scanning ability in a controlled environment prior to tasks on actual wildfires. An infrared scanning assignment was completed in a 100-ha grid in Hinton, AB. The scanning took place after sunset and involved locating 15 to 25 fully exposed hotspots. It was identified that the assessment should take place during one continuous flight, and the selection of the sensor used during the scan was at the discretion of the RPAS vendor. The hotspots used are approximately 116 cm^2 with temperatures between 150 and 300°C.

Identified hotspots were classified based on their radius from the actual hotspot locations that have been determined with a GPS with errors of less than ±10 cm in horizontal accuracy. The hotspots were classified into:

- Positive identification was quantified based on its accuracy to the hotspot's actual location:
    - >15 m from actual location – discounted;
    - 11-15 m from actual location – counted, documented under distance category 11-15 m;
    - 6-10 m from actual location – counted, documented under distance category 6-10 m; and
    - 0-5 m from actual location – counted, documented under distance category 0-5 m.
- False positives.

The RPAS vendor had two hours to detect hotspots and determine their GPS coordinates. The RPAS vendor was expected to provide the evaluator with a KML file containing the following information:

- Breadcrumb trail of the RPA flight during the detection operations;
- Location of detected hotspots; and
- Perimeter of IR grid.

The KML file was expected to be sent electronically to the evaluator. The RPAS vendor was expected to provide a KML file to the evaluator within 30 minutes of landing, and delivery time was documented.

Phase 2: Fire behaviour monitoring

For this phase of the project, the preference was to assess the RPAS vendor on an active wildfire. In the event that evaluation was not possible on an active wildfire, a simulated wildfire scenario was to have been set up as a proxy. A hybrid approach was to be undertaken if fire behaviour activity was relatively less active.

The objective of this assignment was to assess if the RPAS vendor can collect and effectively communicate fire behaviour information that may be of use to the incident command team.

Following the assessment of hotspot detection capabilities of the RPAS in a controlled setting, this assignment assessed the ability to use the RPAS for night-time monitoring of active wildfires. The purpose of this assignment was to document changes in fire behaviour in real time during night operations.

The RPAS vendor conducted a night-time flight over a section of the active wildfire to capture critical fire behaviour data. The RPAS vendor was expected to relay the following information to the evaluator in near real time:

- Rate of spread (ROS) and direction:
  - Provide ROS (m/min) information:
    - Reported in 10-60 minute intervals; and
    - Communicate information to fireline staff either verbally or electronically (fireline staff may be located outside of cellular coverage areas).
  - Provide direction of fire propagation:
    - Reported in 10 minute intervals.
- Change in fire intensity:
  - Provide qualitative information on fire behaviour – surface, crowning, etc.;
  - Provide quantitative information on candling activity:

        - Quantify candling activity based on number of instances of candling per unit length of fireline perimeter (i.e., X candling trees/km of fireline); and
    - Provide real-time full-motion video of fire front.
- Localized fire-perimeter mapping:
    - Provide fire-perimeter map for the assigned area at end of flight and within 30 minutes.
- Change in fire intensity:
    - Qualitative fire behaviour – 10-60 minute intervals;
    - Quantitative fire behaviour – 10-60 minute intervals; and
    - Real-time full-motion video – continuous.
- Real-time (and completed) log of:
    - ROS (with timestamp);
    - Direction of propagation;
    - Qualitative fire behaviour; and
    - Quantitative fire behaviour.
- Real-time full-motion video – Screen-share with evaluator, with permission for screenshots for documentation.

Changes to the methods due to changing fire conditions and extenuating circumstances

Due to insignificant fire activity when the vendor was deployed to Fort McMurray's Martin Complex of fires, a portion of the Phase 2 assessment (fire behaviour monitoring) could not be conducted. Consequently, a Part 2 assessment was added to Phase 1 data collection at Hinton.

Additional assessment criteria and deliverables included:

- Identification of all structures and values within the NOTAM area including:
    - Estimated size of structures; and
    - Deliverable - SHP or KML and CSV for point items.
- Determination of rate of spread simulated by lighting hotspot targets at various distances at set time intervals in an open area:
    - Deliverable - SHP or KML for advancing fire perimeter with time stamps.
- Direction and ROS in m/min with minimum, maximum, and average for each time period:
    - Deliverable CSV.
- Full-motion video transmission.

RPAS vendor information

The RPAS vendor was provided with the following information:

- All methods outlined above;
- Expected deliverables and formats; and
- NOTAM extent and times.
- Site information:
    - Hinton grid extent.

RESULTS

Phase 1: Hinton infrared grid accuracy and efficacy assessment

Part 1: Hotspot accuracy

The vendor and FPInnovations arrived in Hinton on August 10, 2021, to perform an accuracy assessment on their RPAS and supporting equipment. Unfortunately, before the assessment could commence, the RPAS experienced a failure in one of its electronic speed controllers (ESC), which meant that the RPAS was not operational until a new part was received. The vendor did everything they could to secure a part and get in the air as quickly as possible. The vendor received the replacement part from California on the morning of August 12, 2021, and was ready to perform the assessment on the night of August 12.

The daytime high from a weather station near Entrance (station "Entrance Auto") was 27°C and is approximately 12 km from the assessment site. When the assessment commenced, the station was reporting a temperature of 14°C at 22:00 MDT[1] and 8°C by 02:00 MDT on August 13. The elevation of the weather station was 300 m lower than the flight staging area. Therefore, the temperature where the flight took place was likely 2-3°C lower than what was reported at the weather station.

NOTAM information was provided to the vendor prior to deployment in Hinton. The vendor was informed that the NOTAM would be in place from 20:00 to 07:00 and that the assessment would take place between those times. The launch area was located approximately 430 m to the SE of the grid at a local topographic high of ~1300 m. The RPA entered the grid area at 21:37, and at 21:56 the RPA operator was receiving engine overload warnings and had to return to the landing area. The operator emptied some fuel from the RPA to reduce weight and took off again at 22:05.

[1] All times in MDT.

FPInnovations requested that the operator complete the accuracy assessment in one continuous flight; however, the RPA needed to return to the staging area to reduce weight. It is unclear why, considering the RPA took off and landed twice, only one take-off and landing is observed in the breadcrumb trail. The vendor informed FPInnovations that the higher altitude and reduced fuel would shorten the flight time to around 1.5 hours. The RPA landed at 23:00 and finished the assessment after identifying 16 potential hotspots.

The deliverables produced by the vendor are shown in Figures 1 and 2. Potential hotspots identified by the vendor can be seen below in Figure 1. The flight breadcrumb trail can be seen in Figure 2 along with the potential hotspot locations accompanied by their 5-, 10-, and 15-m buffers.

Furthermore, Table 1 shows five potential hotspot locations that were identified within 40 m of a surveyed and lit hotspot location. The table indicates the distance of each identified hotspot from a lit hotspot target, with the minimum distance, the maximum distance, the median distance, and the average distance of the five hotspots that were within 40 m. The other 11 potential hotspot locations were more than 40 m from actual hotspot locations. Fifteen hotspots were lit during the assessment on the grid. The average accuracy for detected hotspots was an 8.5 m radius, with a maximum radius of 11.3 m and a minimum radius of 6.2 m from actual hotspot locations.

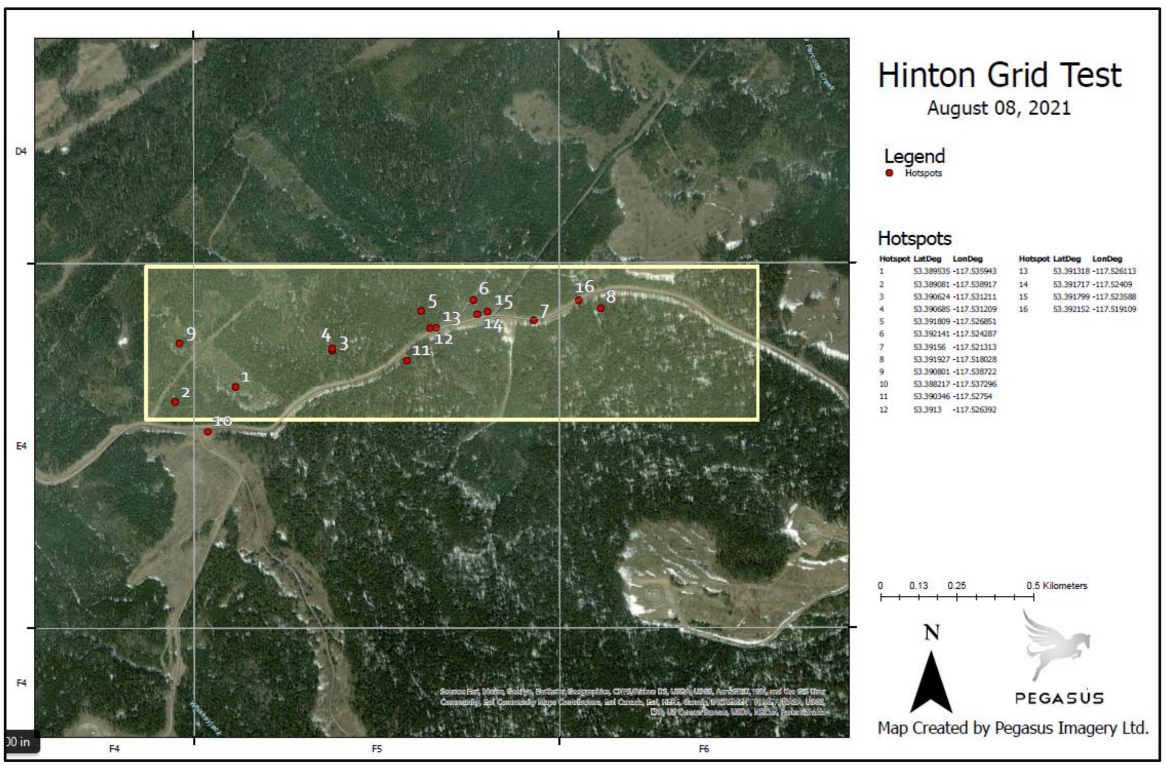


Figure 1: The vendor’s deliverable showing potential hotspot locations.

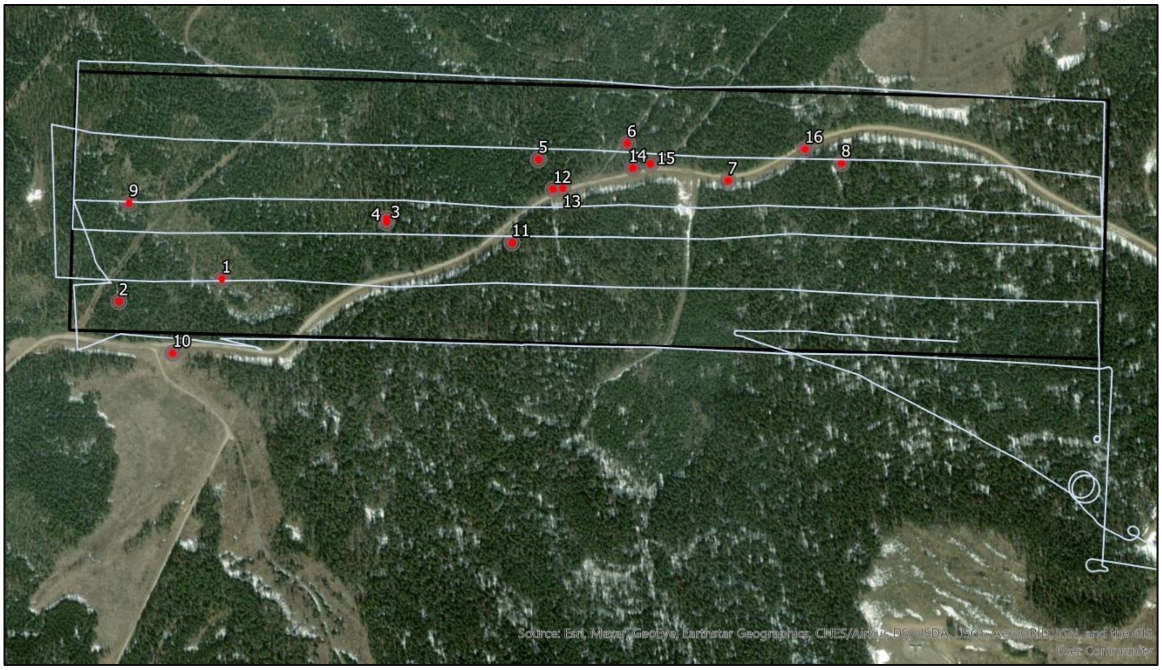


Figure 2: Potential hotspot locations and flight path bread crumb trail provided in KML format by the vendor.

Table 1: Radius statistics of potential hotspot locations within 40 m of an actual hotspot

Potential hotspot	Radius (m)	Radius group
1	11.32161985	10-15 m
2	10.72676515	10-15 m
5	6.196077094	5-10 m
6	6.43097185	5-10 m
9	7.627403888	5-10 m
Minimum	6.196077094	
Maximum	11.32161985	
Median	7.627403888	
Average	8.460567566	

Part 2: ROS simulation

The ROS simulation was started at 00:57 and the most northern point (bottom of Appendix A: Figure 10) was lit. This corresponds to point 1 in Figure 3 and the yellow point 1 in Figure 4. The first row of hotspots was lit at 01:07 and corresponds to points 2, 3, and 4. The second row of hotspots was lit at 01:17 and corresponds to points 5 and 6. Finally, the third row of hotspots was lit at 01:27 and corresponds to points 7, 8, and 9.

The deliverable provided by the vendor (Figure 3) shows the detected hotspots on the map, the perimeters for each time step, the coordinates for each hotspot, and a total rate of spread for the 30-minute elapsed time. Breakdown of measured ROS for each time period can be seen in Table 2 that was created by FPInnovations using the ground distance measurements and angles (Appendix A: Figure 10).

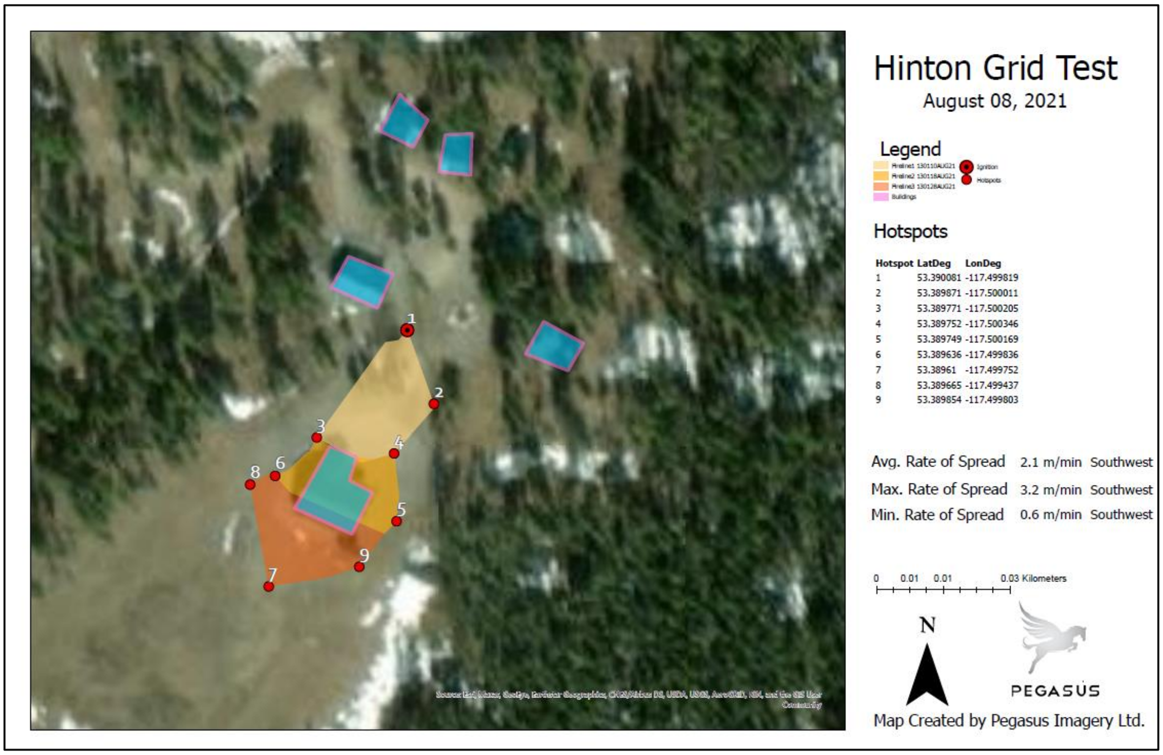


Figure 3: The vendor's map deliverable for ROS simulation.

Table 2: ROS calculations based on ground measurements collected by FPInnovations, measurements can be seen in Appendix A.

Elapsed time (min)	**Hypothetical fire progression at five points along the fireline (m)**					**Min. ROS (m/min)**	**Max. ROS (m/min)**	**Average ROS (m/min)**
10	14.8	20.03	27.1	29.6	31.9	1.48	3.19	2.4686
10	33	24.39	16.13	13.56	12	1.2	3.3	1.9816
10	13.2	20.41	28.86	17.03	10	1	2.886	1.79
					Avg.	1.226667	3.125333	2.080067

Deliverable visible points vs. legend coordinates:

When the coordinates from the map deliverables legend were entered into a GIS program, they did not line up with the coordinates of detected hotspots that were displayed on the deliverable map. It is unclear why these coordinates do not match and, as seen in Figure 4, calculating ROS using these coordinates would not be possible. The coordinates listed in the map legend and those from the points visible on the map are shown in Table 3.

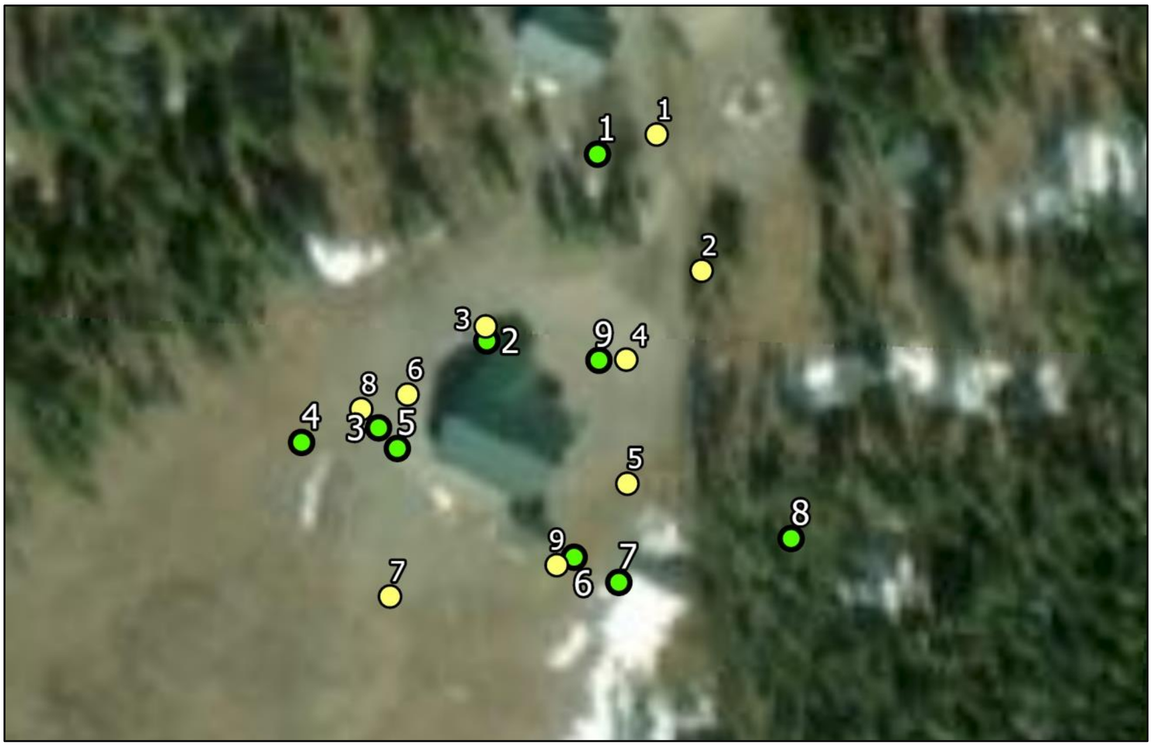


Figure 4: Yellow dots represent those that were visually displayed on the deliverable map. Green dots represent the coordinates from the map deliverables legend.

Table 3: Hotspot coordinates from deliverable map and legend.

Point	Latitude on map	Longitude on map	Latitude from legend	Longitude from legend
1	53.39008	-117.499819	53.39011	-117.4997111
2	53.38987	-117.500011	53.38996	-117.4996194
3	53.38977	-117.500205	53.38989	-117.5000142
4	53.38975	-117.500346	53.38986	-117.4997527
5	53.38975	-117.500169	53.38972	-117.4997426
6	53.38964	-117.499836	53.38981	-117.5001538
7	53.38961	-117.499752	53.38959	-117.500173
8	53.38967	-117.499437	53.38979	-117.5002381
9	53.38985	-117.499803	53.38963	-117.4998676

Deliverable visible coordinate accuracy analysis:

The points visible on the deliverable map were used to conduct an accuracy analysis. GIS software was used to determine the distance from an input point to other points near it. The values were compared to ground measured distances of where the hotspots were located. The ground measurements were completed with a transect tape.

Errors for the line were calculated by subtracting the ground measured distance from the vendor's distance and then divided by two to determine the error of each point in the ROS direction. The value was divided by two because two points would be contributing to the error, and this process would essentially create an average error for those two points in the ROS orientation. The results of this analysis can be seen in Table 4. The average error in the direction of spread for each line is 1.6 m, with a minimum of 0.0 m and a maximum of 4.7 m.

Table 4: Accuracy analysis of visible coordinates compared to ground measured distances

1st point	2nd point	Vendor visible point distances (m)	Ground measured distances (m)	Error (m) ((Vendor distance – measured distance)/2)
1	2	17.60675333	14.8	1.403377
1	4	27.87211919	27.1	0.38606
1	3	31.55678357	31.9	0.171608
2	4	14.30048064	17.5	1.59976
2	5	27.67394413	33	2.663028
3	4	17.73878667	8.4	4.669393
3	6	12.72057716	12	0.360289
5	9	13.23414079	13.2	0.01707
6	8	5.95186265	10	2.024069
7	8	23.25546129	28.9	2.822269
7	9	20.82472785	22.6	0.887636
8	9	30.69157876	34.2	1.754211
			Minimum	0.01707
			Maximum	4.669393
			Median	1.501568
			Average	1.563231

Phase 2: Fire behaviour monitoring

Briefing and area orientation at the Martin Complex

An initial scout team for the vendor arrived in Fort McMurray for a 10:00 briefing at the ICP. The priorities identified by the incident commander were:

1. MWF067
- 0.6-5.32 km from nearest road
2. MWF065
- 18.6 km from nearest road
3. MWF099
- 22.13 km from nearest road

The vendor was provided with the shape files of the Martin Complex fires and was informed that the RPAS operation period would be between 20:00 and 08:00. Desired information delivery time was before 06:30.

The IC requested that the RPAS and crew be flown by helicopter to access fire 99, which was more remote than the other fires within the complex. However, the vendor declined the mission as they required road access for their staging area and equipment. The vendor informed FPInnovations researchers that they are working on a mobile solution for this purpose, but provided no implementation date.

During the day, the vendor travelled with the IC and an FPInnovations researcher to identify launch sites, staging areas, and restricted areas. The vendor informed the FPInnovations researcher that from the initial assessment they could provide coverage of fires 67 and 61 from the Martin Complex.

The radio system used on the RPAS has the ability to extend range with repeaters; however, the vendor was not able to perform this function at the time. If line of sight is maintained, the range is up to 50 km (quote from the vendor). Furthermore, at such distances, the RPAS will need to increase altitude in order to maintain line of sight, due to the earth's curvature the further away it flies.

Findings from July 19

While flying to fire MWF067, the operator needed to increase RPAS altitude to 1000 ft AGL to maintain connectivity. Once the RPA was ~7 km away, connectivity became too weak and relocation of the staging area was required for better connection. The mission used autopilot and manual assist based on the information being relayed to the operators. The radio antenna needed to be adjusted to maintain reception at the further distances. Automatic antenna orientation based on feedback from the RPAS GPS system would potentially increase connection consistency with the directional antenna.

The RPAS has no onboard back-up of data; therefore, if connection is lost, the data the RPAS is still collecting are also lost. Detected hotspots and breadcrumb trails for the scanning mission of July 19 can be seen in Figure 5. The RPAS detected a surface fire and the video of it was reported by an FPInnovations researcher to be useful but no other deliverables were provided as the portion of active fire was too small. The KML files of the hotspots, flight path, and perimeter were delivered to FPInnovations and the IC before the morning briefing.

The vendor completed three missions on MWF067, with the first being a scan, followed by a scan with a closer staging area for better connection, and a final scan of the fire to see if there was any spread. It is unclear why the breadcrumb trail for the flights conducted on MWF067 on July 19 seems to show gaps and only one take-off location.

The fire crews reported that the KML deliverables were not useful since they could not upload them to Avenza on their mobile devices. A geo PDF with the appropriate features would have been more useful. Furthermore, KML is not a useful file type for analysis since it does not have any associated attributes, and several tools within ArcGIS need to be used to modify the symbology. KML files excel in their simplicity, small size, and ease of viewing in Google Earth.

Findings from July 20

The process used for determining the coordinates of hotspots or other values involves lining up the crosshairs on the video feed with the value and clicking the mouse to mark the location. The computer then uses the drone's location, information from the Inertial Navigation System (INS), and elevation information to determine the hotspot's coordinates. The vendor informed FPInnovations that the accuracy of the GPS on their RPA was approximately ±10 m.

The first mission on July 20 was a flight around the perimeter of MWF061 (Figure 6), as it was the only other wildfire in the complex that was sufficiently close to road access given the RPA's current range. No hotspots were found during the mission flown around the periphery of the wildfire area and the RPA returned to the staging area. The furthest the RPA flew from the launch location on any of the flights was 8 km on MWF061 and 7.6 km on MWF067.

The second mission was another flight of MWF067 to determine if there was any spread from the night before. New hotspots were identified but little to no spread was reported to have occurred from the previous night.

Feedback from the crews regarding the accuracy of the hotspots indicated accuracy in the 5-10 m range; however, without surveyed confirmation of these locations, these distances cannot be verified, especially given the density of hotspots located on MWF067. Furthermore, the GPS accuracy on the devices the crews were using, either cellular devices or handheld GPS units, would not have been high enough to confirm location information with greater precision.

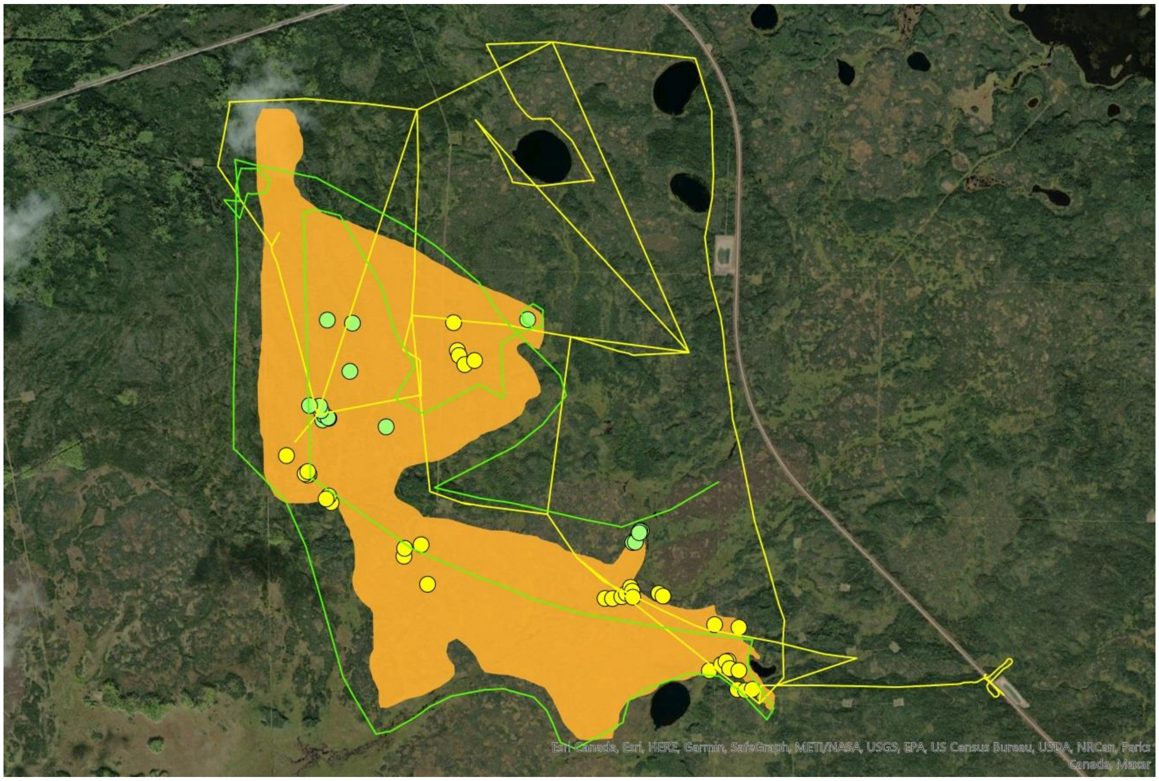


Figure 5: Showing the flight paths, identified perimeter, and identified hotspot locations for both days in Fort McMurray on MWF067. The yellow line breadcrumb trail and yellow hotspots were completed on the night of July 19 and the green were completed on July 20, 2021.

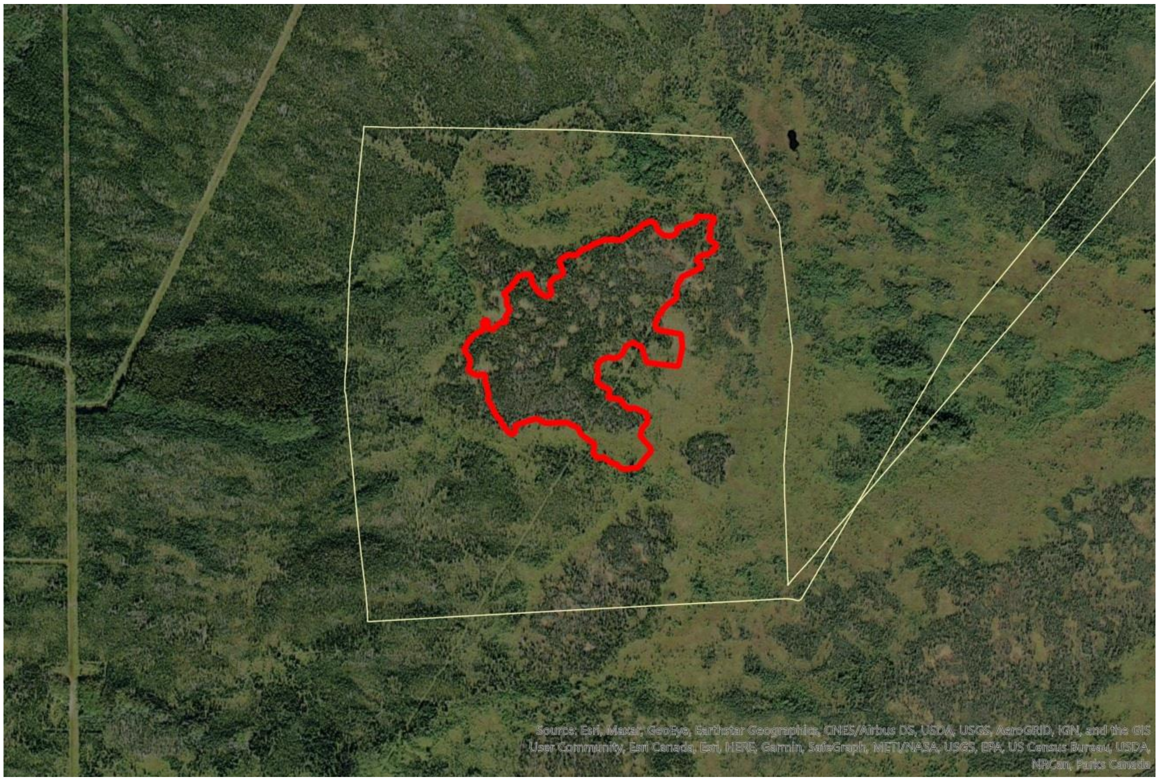


Figure 6: Flight path (yellow line) and identified perimeter for MWF061 from mission on July 20, 2021. No hotspots were found on this flight.

DISCUSSION

Accuracy assessment based on HD45-LV total system accuracy

The following accuracy assessment will only include errors based on the INS of the Trillium Orion HD45LV (Figure 7) and does not include further errors based on GPS, DEM, or other sources. Scenario parameters and their associated horizontal ground error are based on the typical 1.5° total system accuracy and it is unclear if this is a ± accuracy value or an absolute value. For the following tests, it is considered an absolute value; therefore, 1.5° = ±0.75°. The scenarios assume that the accuracy range remains constant throughout the gimbals/systems range.

Figure 7: Perimeter 8 hybrid RPA with HD45-LV payload.

As seen below in Table 5, the range of horizontal error is 1.3-235.1 m throughout the scenarios and 1.3-15.7 m when only looking at nadir errors, depending on the RPA altitude. Furthermore, errors in the other components of the RPA system can compound to increase these scenario-based conditions. Sensors with increased accuracy in their INS would be able to deliver more consistent results. On the other hand, as Table 5 indicates, accuracy can be increased by flying closer to the ground and keeping the camera closer to a nadir position. Capabilities of the sensor package will dictate flight grid patterns and adjustments will need to be made to adequately capture all areas.

The heat and smoke from moderate to high-intensity wildfires may inhibit the RPA from getting close to or above the active flaming front. If the operator is looking to calculate ROS on shorter time scales with rates on a threshold of becoming a higher hazard (~3-4 m/min.), then they will need to position their sensor low and close above the fire to get an accurate ROS. If at a high altitude and at a greater gimbal angle from nadir, the ROS calculations may result in large errors on smaller time scales and may even result in negative or negligible ROS when they are actually in the range of concern (~3-4 m/min.). Elapsed time as short as 10 minutes may be necessary in high-risk scenarios to determine the appropriate mitigation for catastrophic loss, and the required accuracy is within the capabilities of the vendors RPAS, as seen in Table 5.

Table 5: HD45-LV total system accuracy and associated horizontal error range on the ground.

Sensor height (m)	Angle from nadir (m)	Min. (°)	Max. (°)	Horizontal error range (m)
50	0	-0.75	0.75	1.3
50	15	14.25	15.75	1.4
50	30	29.25	30.75	1.7
50	45	44.25	45.75	2.6
50	60	59.25	60.75	5.2
50	75	74.25	75.75	19.6
100	0	-0.75	0.75	2.6
100	15	14.25	15.75	2.8
100	30	29.25	30.75	3.5
100	45	44.25	45.75	5.2
100	60	59.25	60.75	10.5
100	75	74.25	75.75	39.2
300	0	-0.75	0.75	7.9
300	15	14.25	15.75	8.4
300	30	29.25	30.75	10.5
300	45	44.25	45.75	15.7
300	60	59.25	60.75	31.4
300	75	74.25	75.75	117.5
600	0	-0.75	0.75	15.7
600	15	14.25	15.75	16.8
600	30	29.25	30.75	20.9
600	45	44.25	45.75	31.4
600	60	59.25	60.75	62.9
600	75	74.25	75.75	235.1

Phase 1: Hinton infrared grid accuracy and efficacy assessment

Hotspot locations were chosen such that they had an open view of the sky. However, as these locations were in a forested environment, many would not have been visible from an oblique angle. Real wildfire hotspots would be found in a variety of locations ranging from open areas to full coverage under dense conifers or downed woody debris. Therefore, a flight pattern with greater overlap would have been more productive in detecting hotspots and accurately determining their coordinates.

Hotspot detection accuracy and the ability to differentiate hotspots from other items on the landscape can vary greatly between operators. This is one of the main reasons why, in general, individual operators, and not entire vendors, are certified for hotspot detection while completing the evaluation by Wildfire Management on the Hinton hotspot grid. As previously discussed, the flight pattern and gimbal angle can have significant impacts on the accuracy of the hotspot location. The operator needs to consider these factors when attempting to determine the most accurate coordinates and minimize sources of error when possible. Furthermore, proficiency in sensor operation is particularly valuable to help distinguish between other objects that might emit a thermal signature on the landscape. Infrared imagery does not directly measure an object's temperature, but rather it uses a series of correlations relating to the assumed thermal properties of an object and radiometric characteristics; it determines the relative temperature of objects in the scene. Only calibrated cameras can attempt to measure an object's absolute temperature values. This means that objects with different properties can present as false positives and appear to be similar in temperature and shape to actual hotspots.

The requested deliverables for this phase of the RPAS evaluation included:

- Identify all structures and their size and other values within the NOTAM area;
- Report advancing fire perimeter at 10-minute intervals with time stamps on a map;
- ROS and direction in m/min with minimum, maximum, and average for each time period; and
- Full-motion video transmission.

Deliverables not provided by the vendor:

- Identify all structures within the NOTAM area;
- Provide ROS with minimum, maximum, and average for each time period (only total for the entire time was reported); and
- Provide full-motion video transmission to individuals outside of cell coverage and without a Google account login.

Further assessments with other vendors may help to determine if the deliverables requested were reasonable and substantiate whether they can be delivered. However, with only one vendor and one assessment, this is difficult to determine at this time.

When the vendor arrived in Hinton for the evaluation, they received notice from their pilot that the RPA was not operational due to a failed ESC. The vendor informed FPInnovations that they were not able to get the RPA flying because the RPA supplier restricts extra parts. The RPAS manufacturer (Skyfront) is reported to only ship necessary parts and no surplus parts inventory can be supplied. The vendor informed FPInnovations that they are working on an agreement with Skyfront to be their Canadian distributor, which would allow them to have a supply of spare parts.

Phase 2: Fire behaviour monitoring

Mobility and range

The RPAS was only able to access the highest priority wildfire in the Martin Complex. The second and third priority wildfires would have required increased RPAS range or the ability to load the RPAS and all necessary equipment into a helicopter. The vendor has stated they are working on solutions to both of these issues.

Increasing the RPAS range would be the most straightforward solution, as there are several problems associated with transporting the equipment to another location by helicopter.

One of the key concerns with transporting a crew closer to an active wildfire is safety. To provide optimum value, RPAS intelligence gathering should be completed at night or very early in the morning, because this is when IR imaging is most effective. However, if the team were to be transported by helicopter to a location where they would be within range of the active wildfire, they would need to be in a location that is safe from the wildfire. As helicopter use within a wildfire is generally limited to daylight operations, the RPAS team would be left alone overnight in a remote location with limited extraction potential. Instead, if the RPAS range is increased, the team can remain more mobile and have more options to return to a safe location if fire behaviour were to change. Wildfires can experience overnight growth that exceeds the current operational range of the vendor's RPAS.

Increasing the RPAS range would likely require an automated directional antenna in combination with a tall mast to raise the signal above any surrounding vegetation. However, this would be difficult to do in areas with undulating terrain that can easily be higher than a truck-mounted, reasonably sized mast. An alternative solution would be to use an RPAS or several RPASs to relay the signal to the main RPAS. This would require the base RPAS to hover higher in areas with more topographic relief and when the main RPAS is further away. Depending on the operation set-up, this may require another pilot, though the hovering RPAS should have a much lighter payload and thus could remain in the air for at least as long as the main RPAS. Another option could be a tethered RPAS, which is supplied power from a lightweight cable attached to a power supply, which would allow it to remain in the air indefinitely over the staging area.

Flight time

Skyfront states that the RPAS has a five-hour flight time with no payload at sea level. The Martin Complex wildfires had an elevation around 500 m ASL and RPAS flight time was not significantly impacted. The vendor informed FPInnovations that the flight time would be around 2.5 hours with the payload; however, this is likely an estimate based on manufacturer tests. The maximum flight time that FPInnovations observed while assessing the vendor's RPAS was 1.5 hours, which can be seen in Table 6. However, at the higher elevation of the Hinton hotspot grid, the RPA needed to carry a reduced fuel load in order to stay airborne at the increased altitude. Consequently the increased elevation and payload weight at the increased elevation seemed to cause a significant drop in the top speed of the RPAS. The RPAS seemed to be limited to flight speeds below 10 km/hr during the flights. This should not be an issue on fires at lower elevations.

Fire behaviour

Qualitative and quantitative fire behaviour metrics were not documented because there was no active fire. Only a very small portion, a few metres long, was burning, which did not allow for any reporting or comparison. In order to determine some aspects of what the deliverables might look like, additions were made to the accuracy assessment phase in Hinton. However, future assessments with other vendors will substantiate whether deliverables such as those mentioned in the methods can be delivered upon.

With further assessment of other RPASs it may be become evident that the RPAS platform can collect necessary and beneficial intelligence that will support operational decision-making. However, much like the current hotspot certification process that the Government of Alberta conducts on its hotspot scanning grid, the processing of fire behaviour data will vary widely between operators depending on their knowledge of, and experience with, wildfires and thermography. Furthermore, having a solid background in wildfire behaviour will be fundamental in providing valuable deliverables relating to metrics such as head fire intensity and smoke column characterization.

Logistics and cost

The total cost for the five flights on the Martin Complex fires with a cumulative flight time of 5.6 hours (Table 6) was $25,740. The total cost for the three flights on the Hinton grid with a cumulative flight time of 1.9 hours (Table 6) was $15,537. The average cost per flight hour for the two phases of the project combined was $5,504. These hourly cost could potentially be reduced on longer deployments, as the mobilization and advanced planning costs would only be charged once.

Table 6: Duration of flight performed by the vendor.

Date	Flight time (hr)
July 19, 2021	0.67
July 19, 2021	1.67
July 19, 2021	0.92
July 20, 2021	0.83
July 20, 2021	1.50
August 12,2021	0.32
August 12, 2021	0.92
August 12, 2021	0.67
TOTAL	7.49

Vendor interactions

Interactions with the vendor were positive. The email correspondence was prompt and professional, and all of FPInnovations' questions were answered appropriately. When in the field, they were professional, punctual, and set-up well ahead of when needed. They were prepared to spend the night where they needed to and were equipped with necessary camping and generator supplies to do so.

CONCLUSION

This assessment shows that some areas of RPAS operations need to be addressed and improved upon in order to be useful in a wildfire operations environment. The vendor assessed in both phases has not been evaluated using the protocol for the Government of Alberta's Hotspot Detection Grid, and the results obtained during this investigation should not be extrapolated to how the vendor would perform in that evaluation. Both phases were completed under considerable time constraints and may not represent the full abilities of the vendor or the technology being evaluated. Future investigations may provide greater insight to the capabilities of this vendor and other vendors for the utility of RPAS and associated technology in a wildfire environment. Different technologies and flight paths can result in large differences in results and as such further evaluation is necessary. Future evaluations should focus on surveyed points for ROS simulation on a larger scale with a portion specifically to validate deliverables that would pertain to the flaming front.

APPENDIX A: ADDITIONAL FIGURES

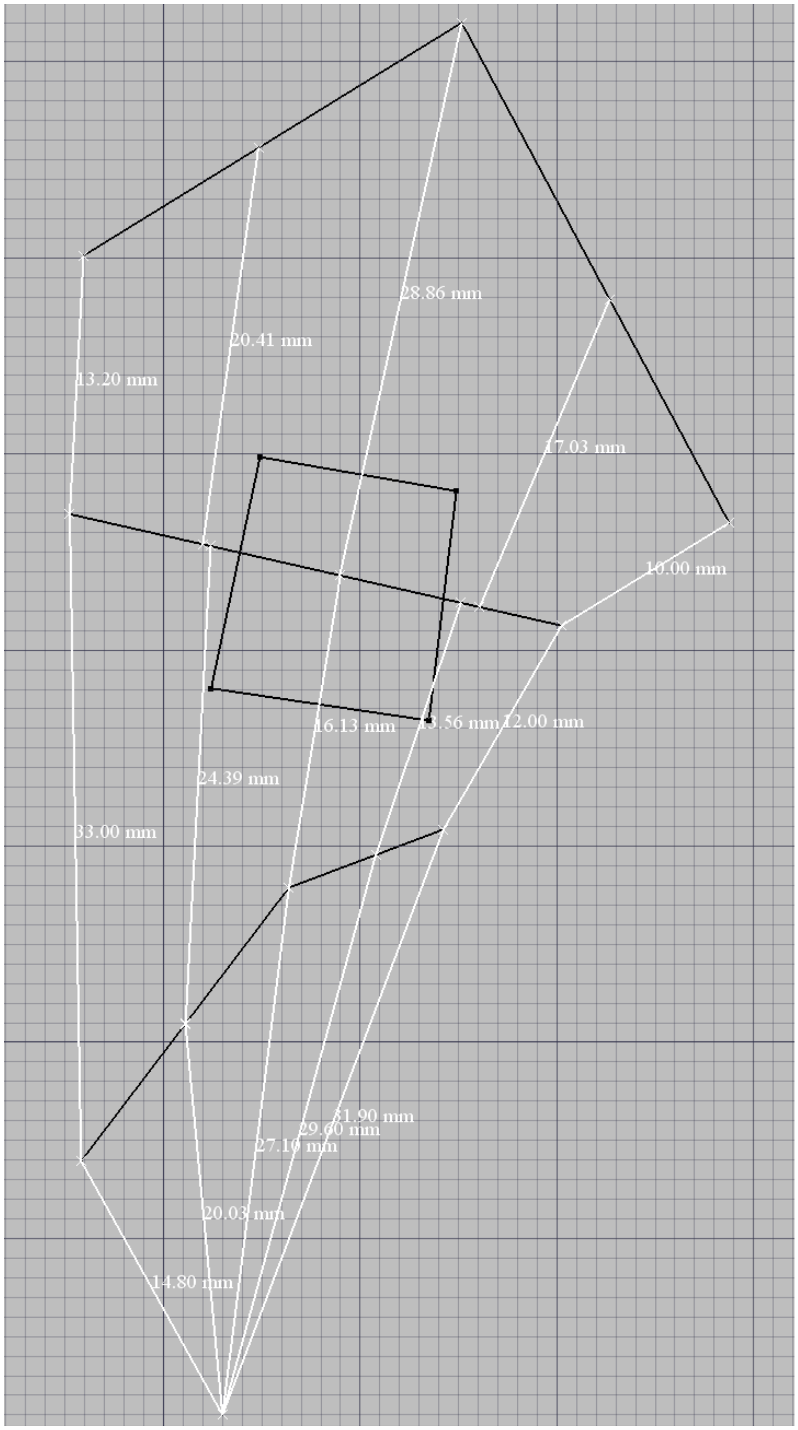


Figure 8: CAD reconstruction of ground measurements for ROS simulation. Measurements are reported in mm and each mm represents 1 m of actual distance.

APPENDIX B: FIRE WEATHER FOR MARTIN COMPLEX

Table 7: Fire weather conditions and predicted fire behaviour for July 19 and 20, 2021

Date	July 19, 2021	July 20,2021
Max. temp	24	23
Low RH %	50	55
Wind	S10	SE10
Lightning	L	L
FFMC (Ells)	85	84
DMC (Ells)	91	91
DC (Ells)	330	320
ISI (Ells)	2	3
BUI (Ells)	72	107
FWI (Ells)	8	14
Intensity class C-2 (Ells)	5	4
ROS C-2 (Ells)	4	3
Fire type C-2 (Ells)	IC	IC

APPENDIX C: SENSOR PACKAGE AND RPAS DETAILS

Trillium Orion HD45-LV:

- Built-in GPS/INS;
- Inertial navigation systems (INS) 1.5° (typical) total system accuracy;
- Geopointing and geolocation;
- 200 Hz calculations;
- Dual GPS support over serial or Ethernet;
- 1,200 g (2.65 lbs.);
- 720p global shutter visible camera;
- FLIR Boson 640 with 36-mm lens:
  - FOV 12.2° with digital zoom to 3.1.

Skyfront Perimeter 8 RPAS:

- Gas-electric hybrid drone;
- 1-hour flight time with 7.5-kg payload (max.) at sea level;
- 2-hour flight time with 5-kg payload at sea level;
- 5-hour flight time with no payload at sea level;
- Maximum tested wind speeds of 35 km/hr;
- Cruise speed of 35 km/hr;
- Max speed of 57 km/hr;
- Minimum temperature of -10°C; and
- Maximum temperature of 45°C.

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